Sveučilište u Zagrebu
Fakultet kemijskog
inženjerstva i tehnologije

FKITMCMXIX

Od otpada do biorazgradljive ambalaže: Inovativna rješenja za održivu budućnost

Izv. prof. dr. sc. Dajana Kučić Grgić
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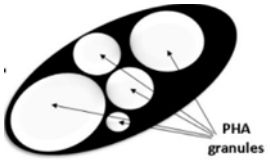
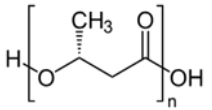
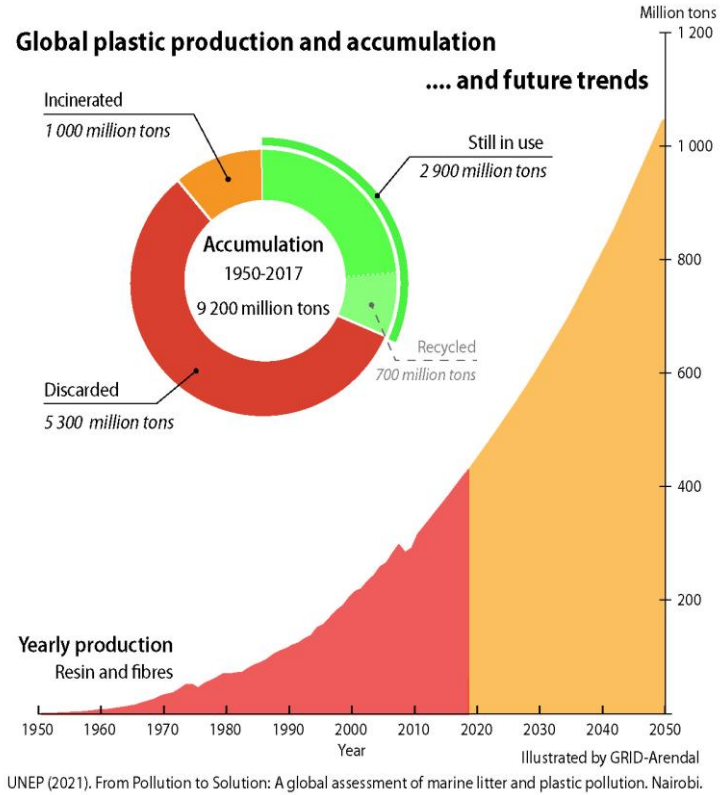
Zagreb, Ožujak 2025.



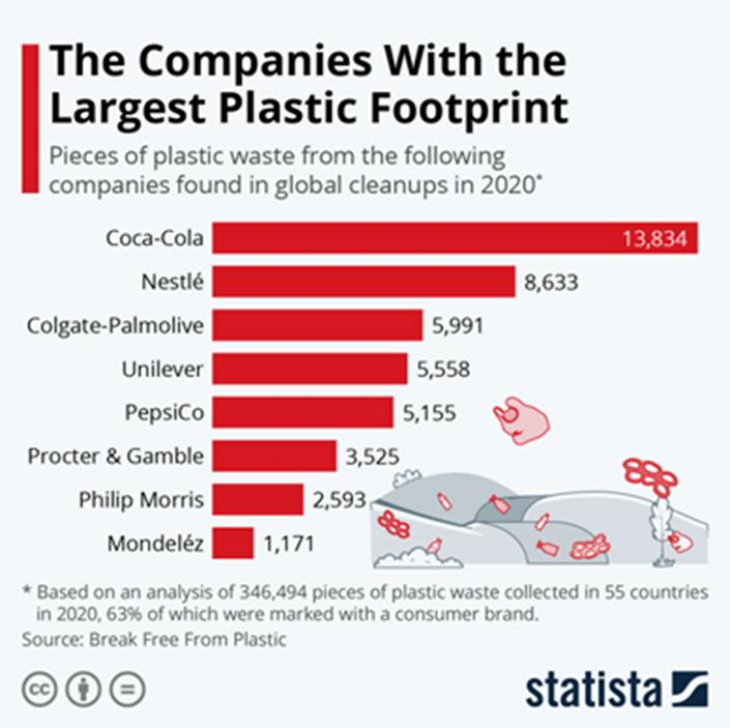


This research was conducted as part of the project „Production and development of compostable packaging from waste biomass for the packaging of industrially processed food products” (**NPOO.C3.2.R3-II .04.0059**) funded by National Recovery and Resilience Plan (funded by the European Union, NextGenerationEU).

Proizvodnja plastike

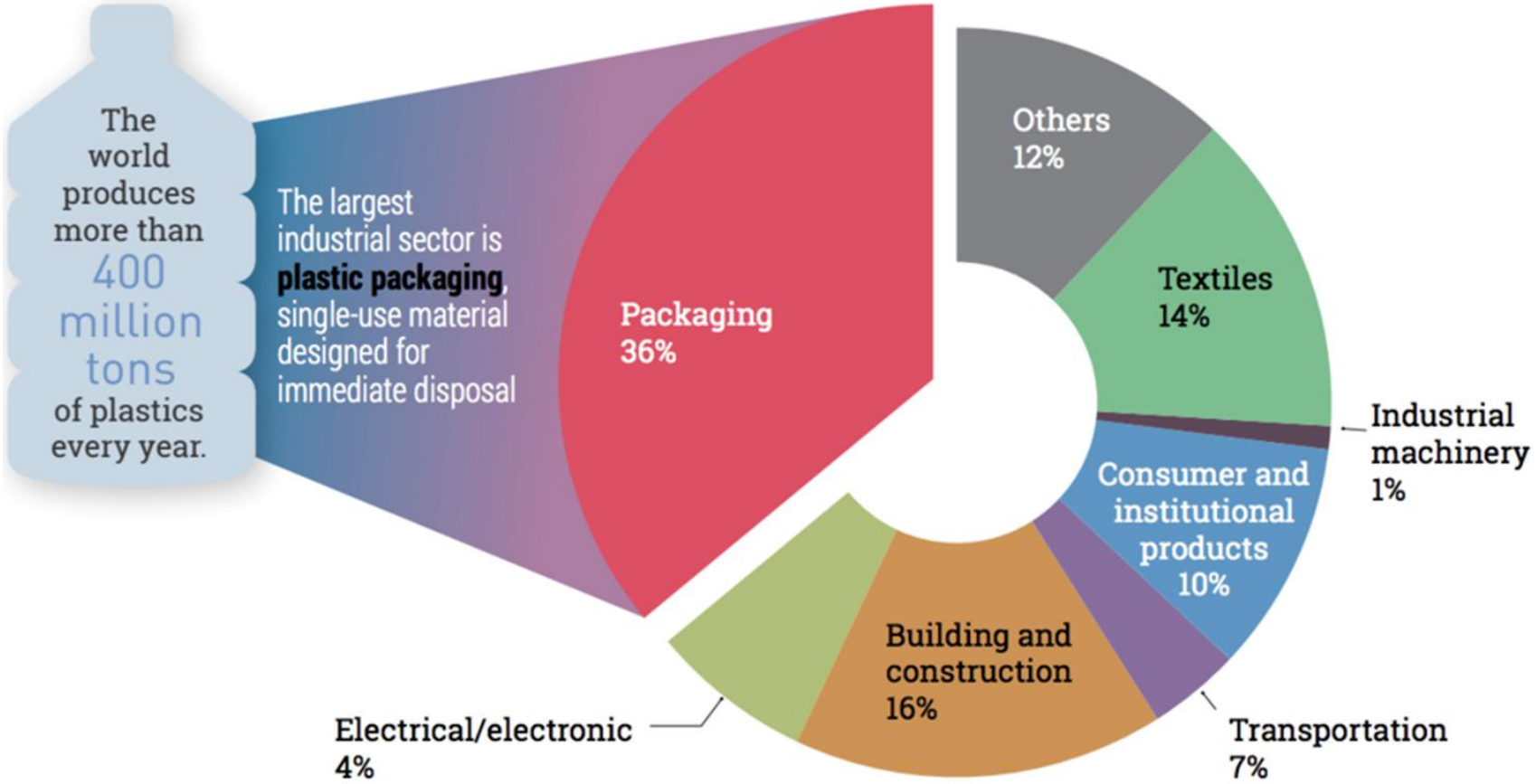


UNEP (2021). From Pollution to Solution: A global assessment of marine litter and plastic pollution. Nairobi.

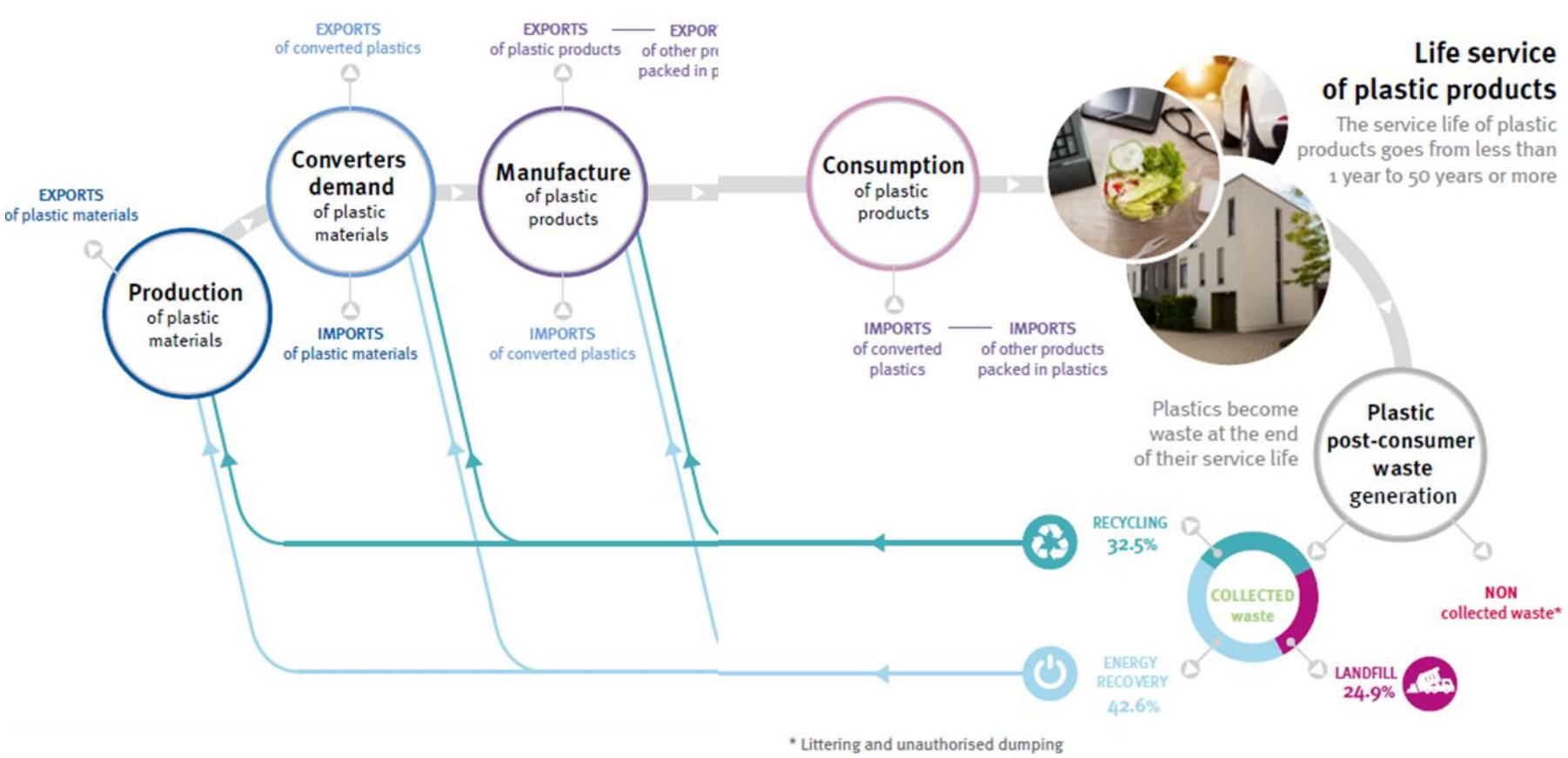


- ✓ *The global production of plastic materials increased tremendously; from ~1.5 million tons in 1950 up to 335 million tons in 2016*
- ✓ *Projections: in 2030, plastic production will double compared to 2016*

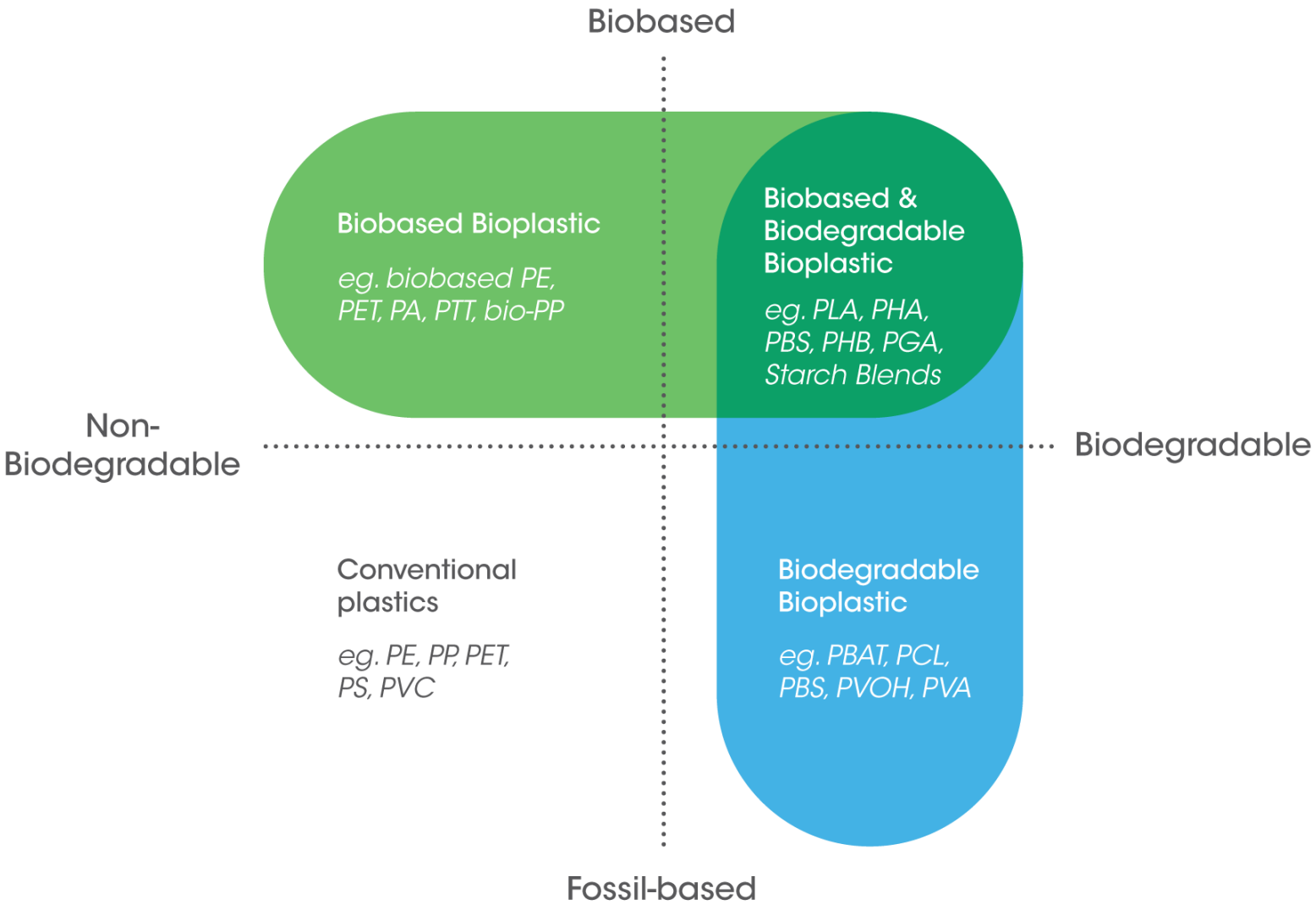
Primjena palstike u različitim sektorima



Kruženje plastike

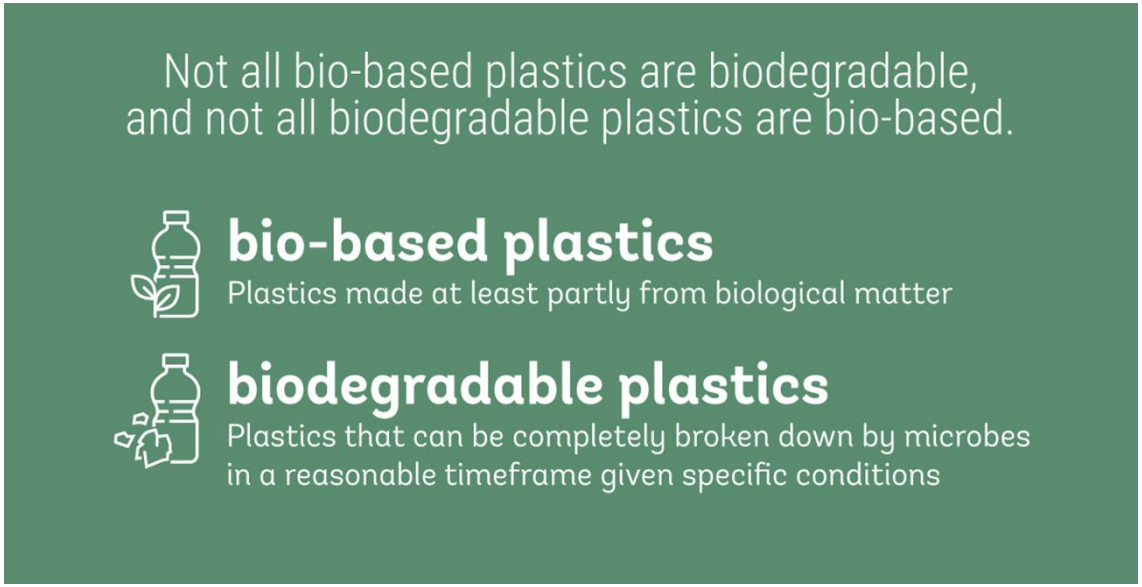


Plastika

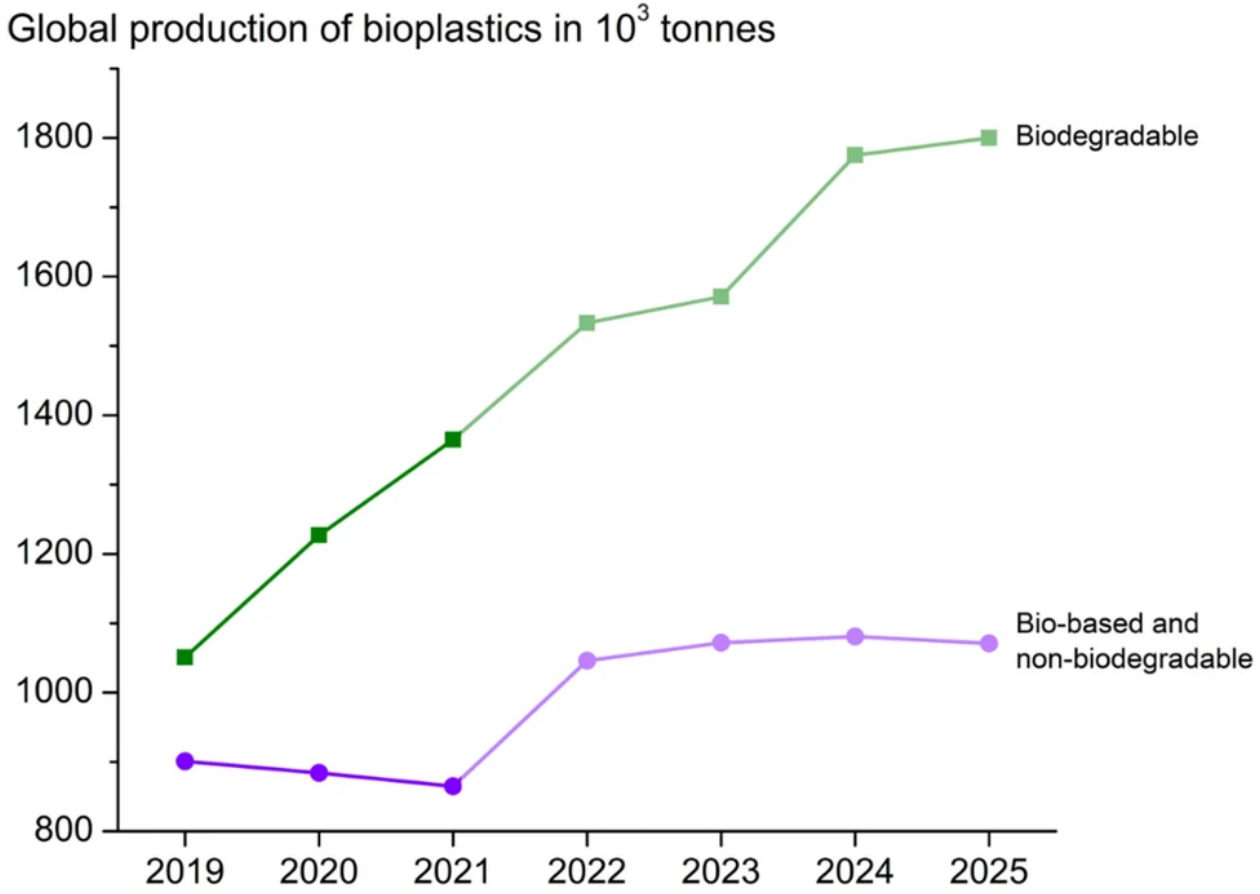

Biobased
Biobased Bioplastic
eg. biobased PE, PET, PA, PTT, bio-PP
Biobased & Biodegradable Bioplastic
eg. PLA, PHA, PBS, PHB, PGA, Starch Blends
Non-Biodegradable
Biodegradable
Conventional plastics
eg. PE, PP, PET, PS, PVC
Biodegradable Bioplastic
eg. PBAT, PCL, PBS, PVOH, PVA
Fossil-based

✓*'Biobased' does not equal 'biodegradable'*

- *The **property of biodegradation** does not depend on the resource basis of a material but is rather linked to its chemical structure*
- *100 percent biobased plastics may be non-biodegradable, and 100 percent fossil based plastics can biodegrade.*

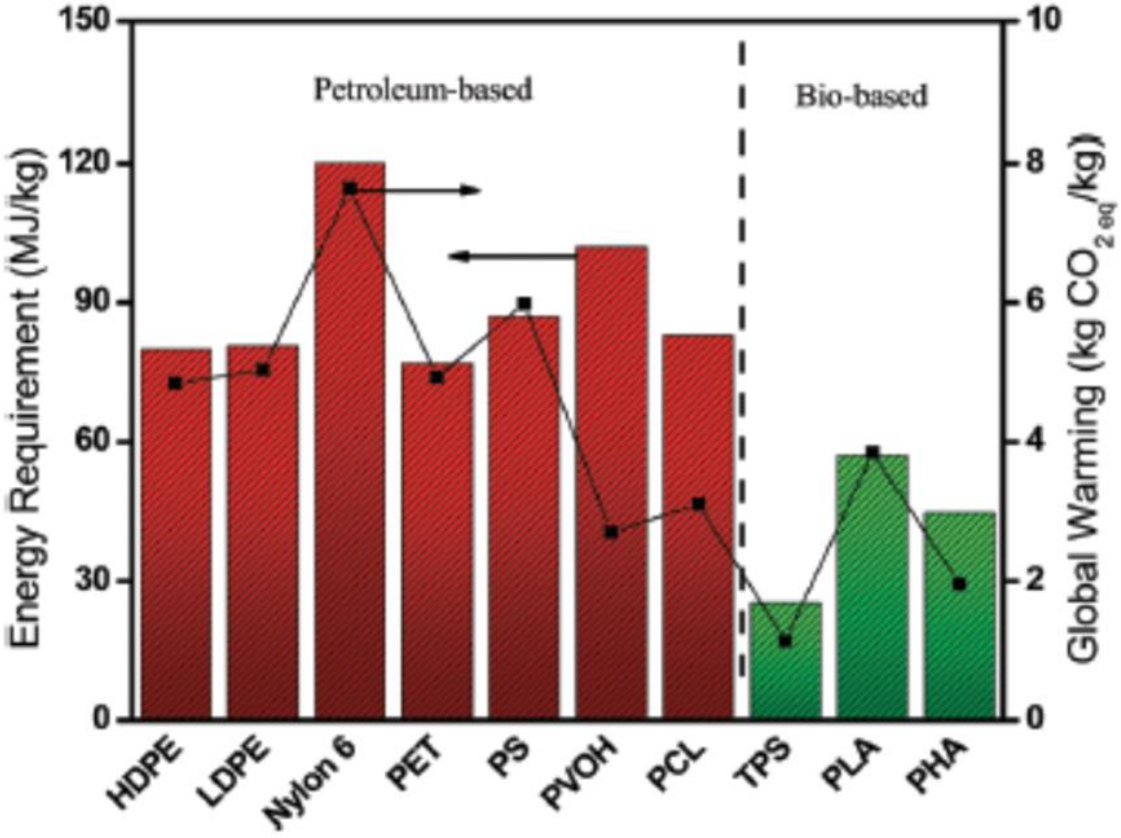


Bioplastika



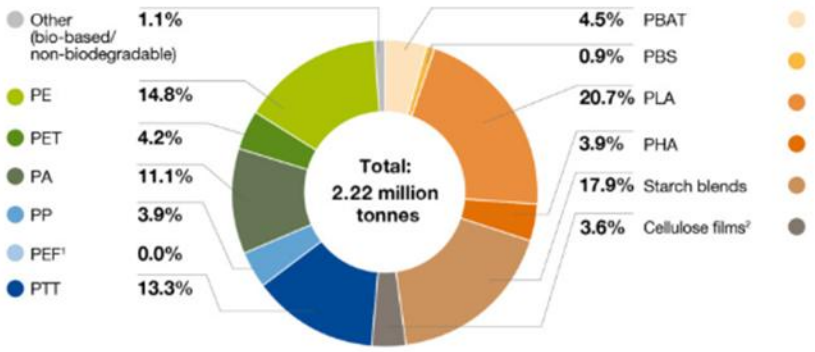
Nanda, S., Patra, B.R., Patel, R. et al. Innovations in applications and prospects of bioplastics and biopolymers: a review. Environ Chem Lett 20, 379–395 (2022). https://doi.org/10.1007/s10311-021-01334-4

Bioplastika



Bioplastika

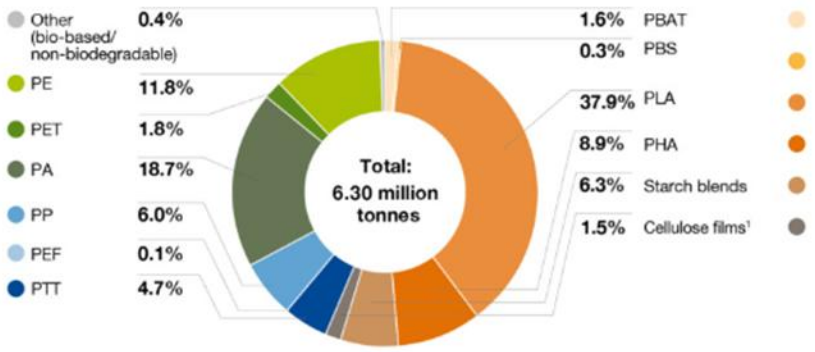
Global production capacities of bioplastics 2022
(by material type)



¹PEF is currently in development and predicted to be available at commercial scale in 2023. ²Regenerated cellulose films

Source: European Bioplastics, nova-Institute (2022). More information: **www.european-bioplastics.org/market** and **www.bio-based.eu/markets**

Global production capacities of bioplastics 2027
(by material type)

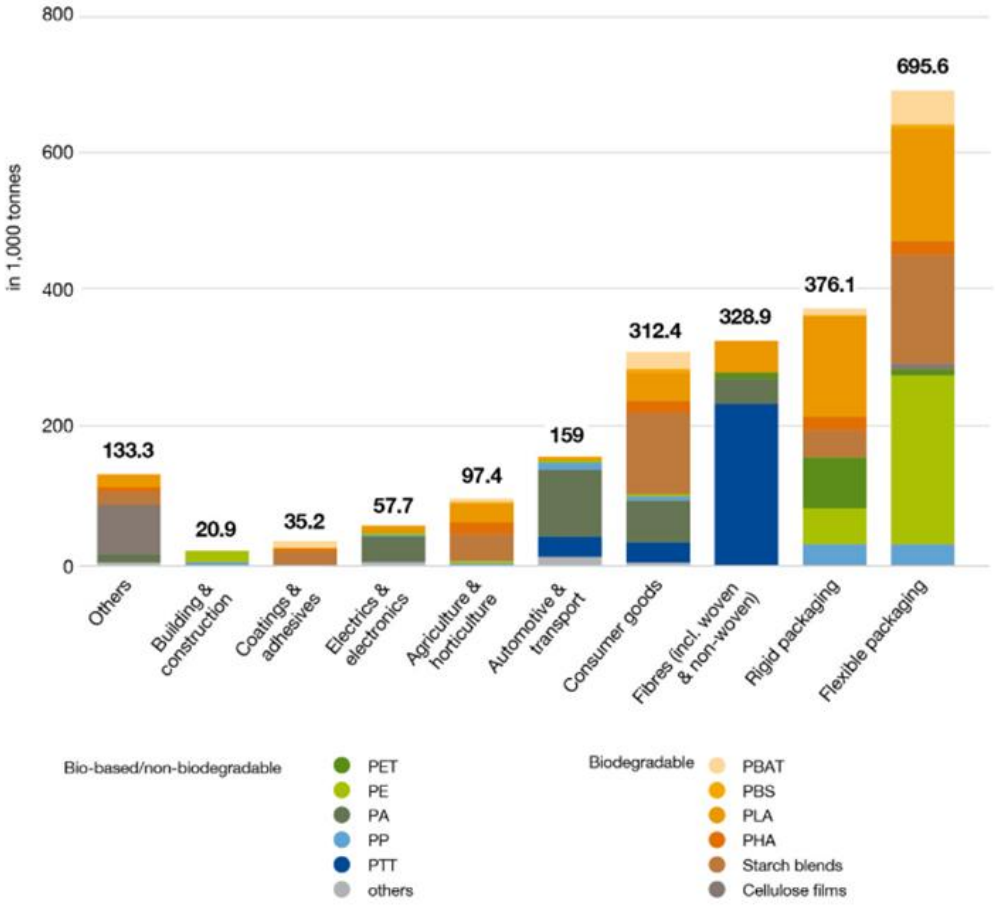


¹Regenerated cellulose films

Source: European Bioplastics, nova-Institute (2022). More information: **www.european-bioplastics.org/market** and **www.bio-based.eu/markets**

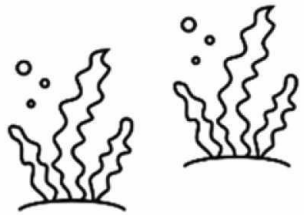
Bioplastika

Global production capacities of bioplastics 2022 (by market segment)



Source: European Bioplastics, nova-Institute (2022). More information: **www.european-bioplastics.org/market** and **www.bio-based.eu/markets**

Proizvodnja bioplastike iz biomase

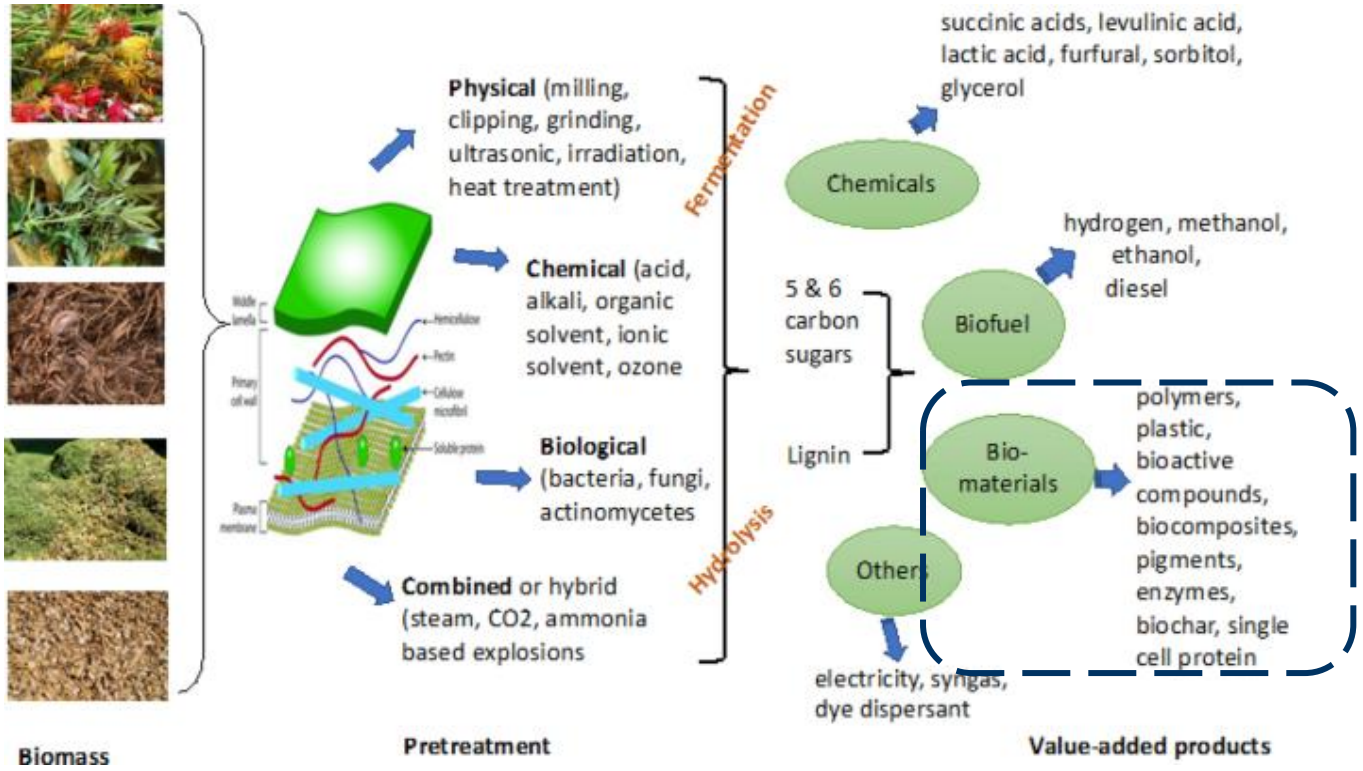
First-Generation	Second-Generation	Third-Generation	Fourth-Generation
			
Edible biomass	Non-edible biomass	Algal biomass	Electrical driven
Sugar beet, wheat, corn, potatoes, canola	Miscanthus, switchgrass, rice straw, rice husk, saw dust, municipal waste, animal by-product streams	Microalgae, macroalgae	Polarized electrodes as electron source

There is a clear trend in research showing a shift to second-generation feedstock usage, due to concerns about available quantities and food prices.

High abundances of second-generation feedstocks and lower market competition lead to lower prices.

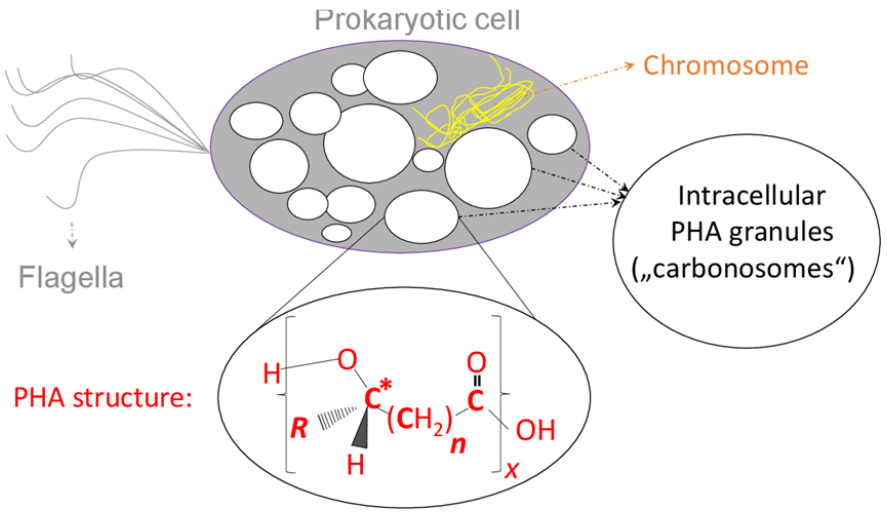
Potential problems: *the economic feasibility of microalgae production, such as difficult culture conditions, high contamination risks, complex cleaning processes as well as low cell densities and productivities*

Proizvodnje bioplastike iz biomase

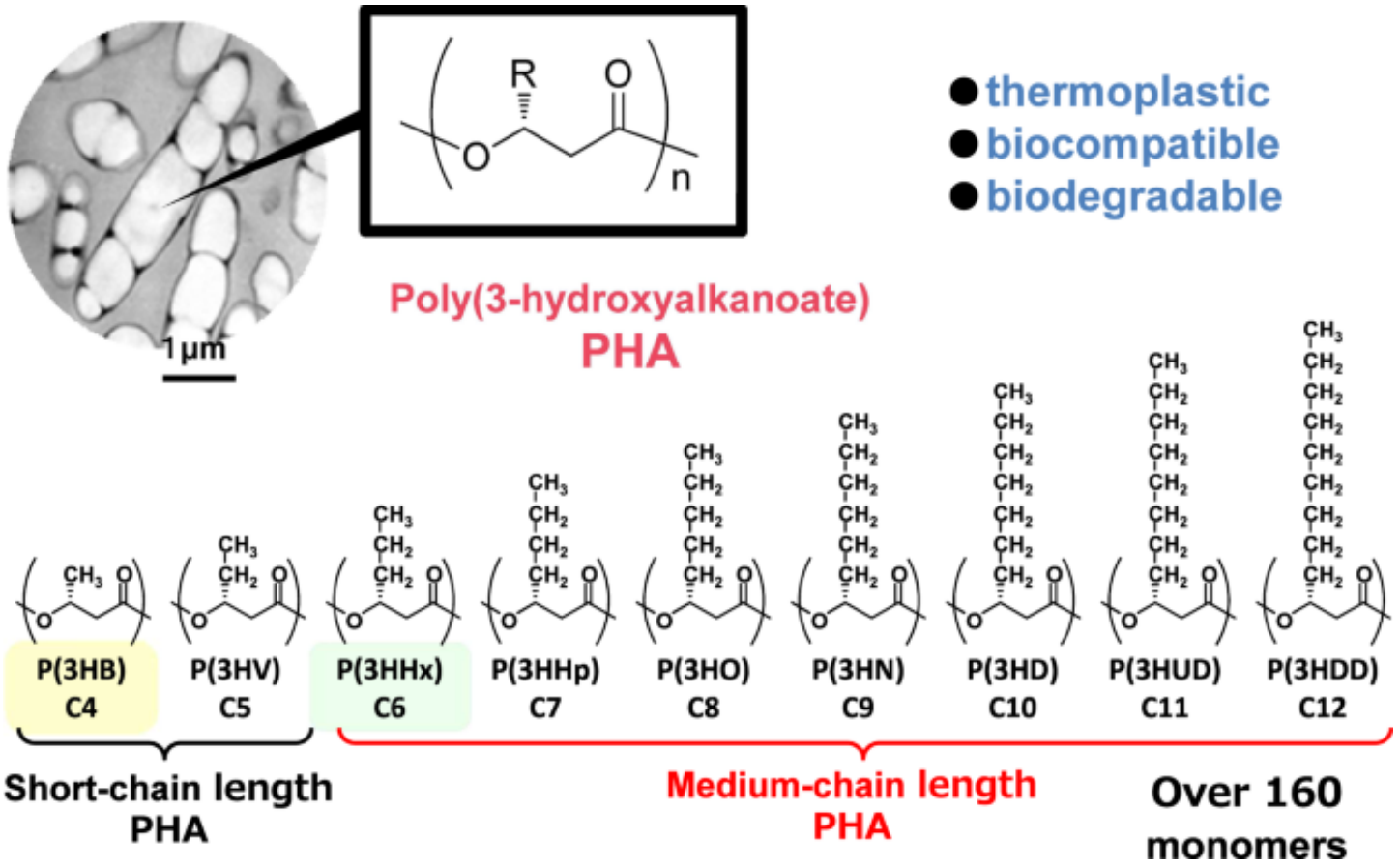


Polihidroksialkanoati

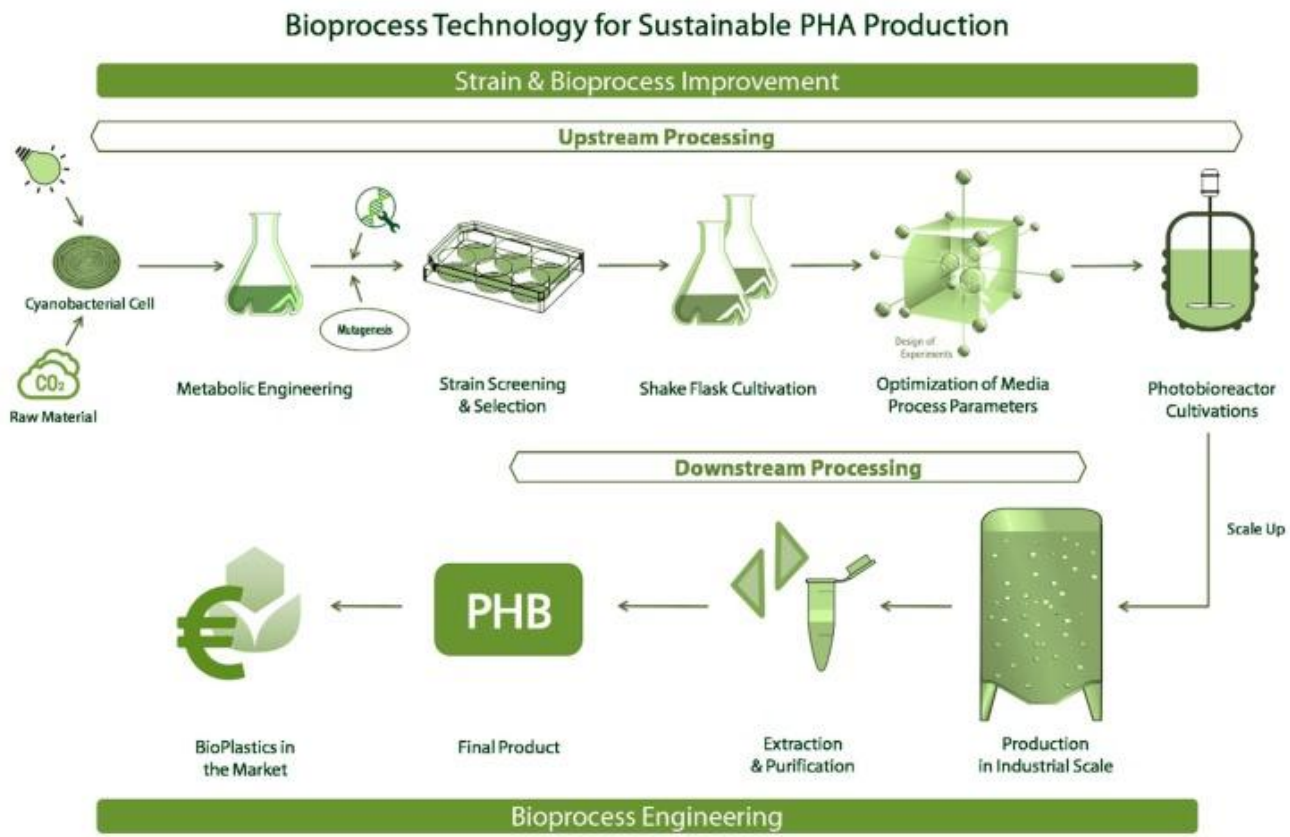
Polihidroksialkanoati (PHA) su ***biorazgradivi polimeri*** *koje prirodno proizvode mikroorganizmi kao odgovor na stresne uvjete okoliša, poput* ***nedostatka hranjivih tvari*** *i viška ugljikohidrata. PHA se smatra održivom alternativom konvencionalnim plastifikatorima, jer su* ***biokompatibilni, netoksični i potpuno razgradivi u prirodi.***



Polihidroksialkanoati



Dobivanje PHA - SmF



https://bio-pha-com-f-pack.eu/

PROJECT - Production and Development of Compostable Packaging from Waste Biomass for the Packaging of Industrially Processed Food Products

1. *Production of PHA from secondary generation biomass – agroindustrial waste using solid state fermentation*
   - *Physical and cehmical characterisation of waste*
   - *Examine pure and mixed culture*
   - *Examine different extractions methods*
   - *Optimization of process via SmF and SSF*

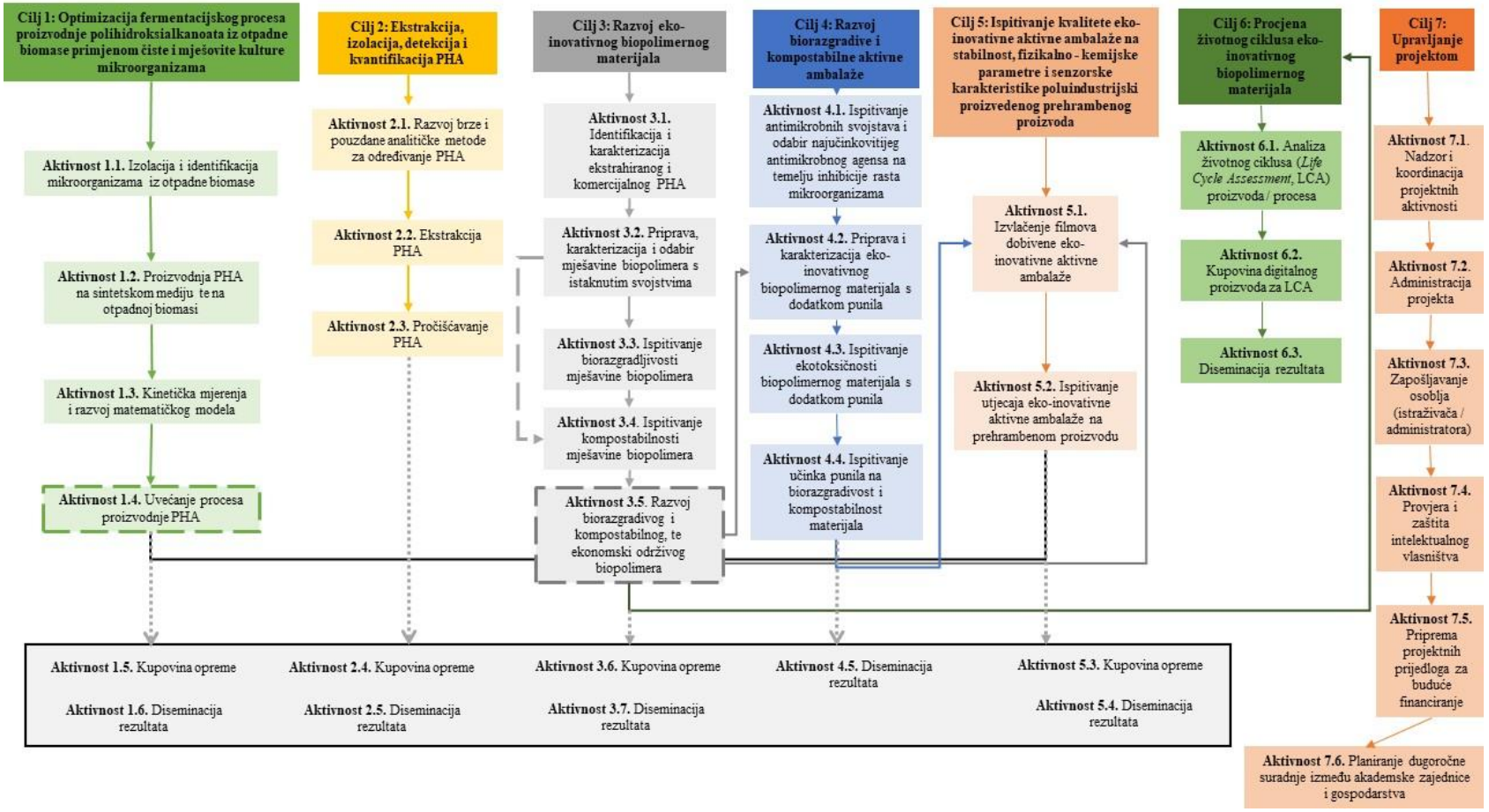
2. *Production of biodegradable and compostable packaging materials*
   Development of biofilms – PHA, PLA, TPS, PBS
   - *Using compostable coatings*
   - *Biodegradable additives*

   Examine of produced biofilms:
   - *biodegradability*
   - *Ecotoxycity*
   - *Compostability*

PTF Podravka GRUPA ROTOPLAST

Financira Europska unija NextGenerationEU

Project activities



Financira Europska unija NextGenerationEU

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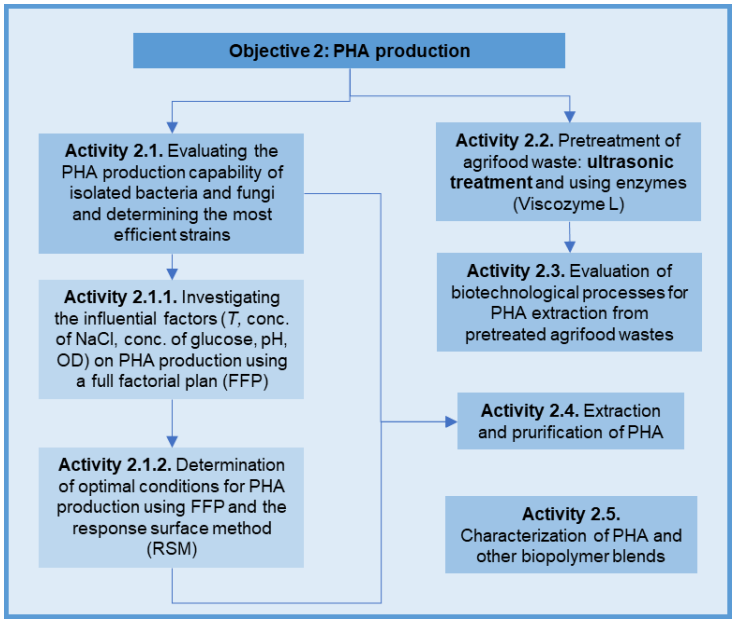
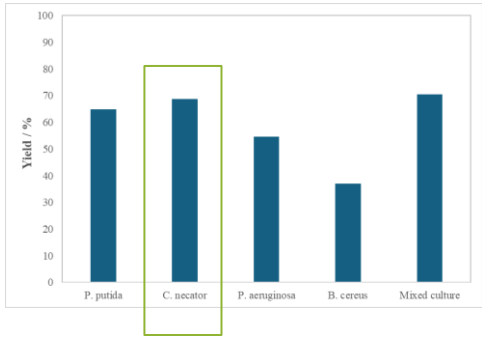
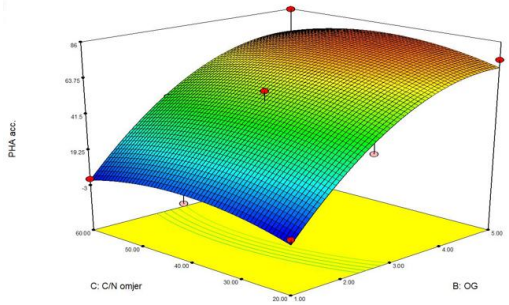
1. Production of PHA by SmF and SSF



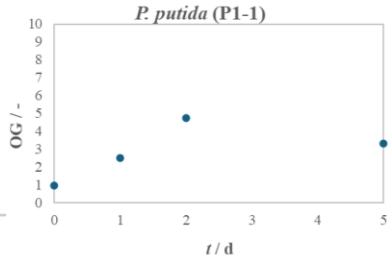
SmF

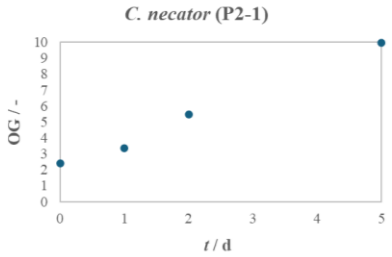


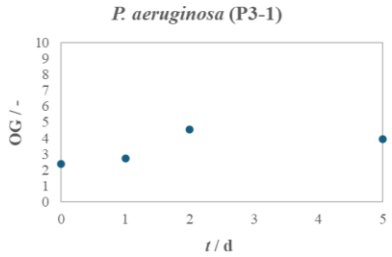


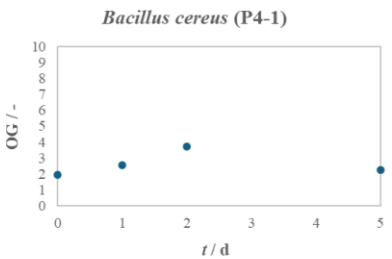
Optimized conditions

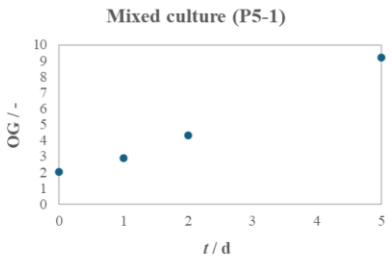
$V_{bioreactor} = 25\ L$











University of Zagreb Faculty of Chemical Engineering and Technology
PTF Podravka ROTOPLAST
Financira Europska unija NextGenerationEU
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Dobivanje PHA - SmF

1. Proizvodnja PHA - SSF

Substrates


Shredded starch


Shredded chickpea (chickpea 1)


Shredded chickpea with bean residues (chickpea 2)

STEP 1 – Isolation of microorganisms

- **Bacteria**
- **Fungi**
  - Yeast

STEP 2 – Identification of microorganisms

- Gram staining
- Sudan black staining
- KOH test
- Biochemical tests: catalase, oxidase and nitrate-reductase tests
- API Strips

- Sudan black staining
- API 20 C aux

STEP 3 – Solid – state fermentation (SSF) and extraction and purification of PHA

- The SSF was performed for 7 days at room temperature
- The SSF was carried out for:
  - starch
  - chickpea 1
  - chickpea 2
  - mixture of starch, chickpea 1 and chickpea 2
  - sterilised mixture of starch, chickpea 1 and chickpea 2
- to 100 g of each substrate and mixture, 10 mL of suspension of mixed culture was added
- to 100 g of sterilised mixture of starch, chickpea 1 and chickpea 2, 10 mL of *Cupriavidus necator* suspension was added
- After SSF, the substrates were centrifuged and dry cell weight (DCW) was determined
- Extraction and purification of PHA was performed with chloroform and 4% sodium hypochlorite

STEP 4 – Characterization od PHA

- **FTIR – ATR spectroscopy**
  - wavelenght range: 4000 – 650 cm^{-1}
- **DSC**
  - 5 – 7 mg of samples
  - 5 cycles of heating and cooling
- **TGA**
  - 5 – 7 mg of samples
  - 40 – 700 ^{0}C

Agroindustrial waste


Cucumbers


Beets

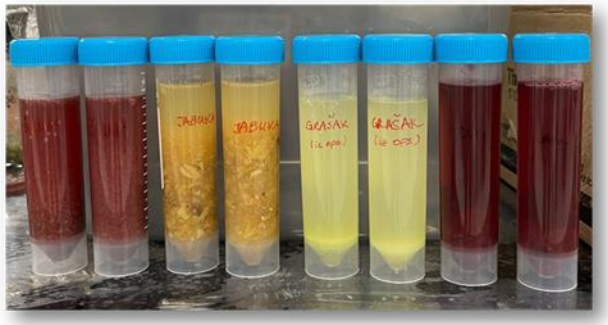

Tomatoe


Starch, Checkpea


Beans


Apple


Plum



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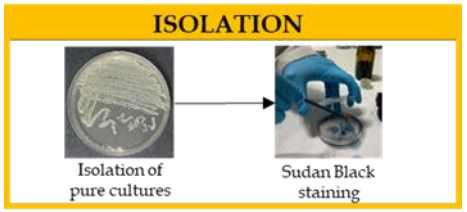
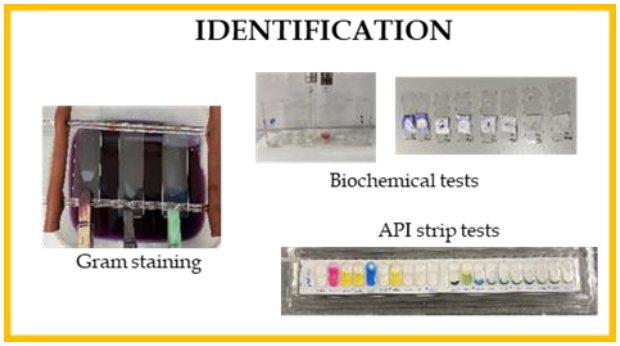
1. Proizvodnja PHA - SSF





Substrate	Identified Microorganism	Morphology
Chickpea 1	*Brevibacillus* sp.	Transparent with flat elevation, and regular round configuration, rod shaped
	Empedobacter brevis	Orange with flat elevation, and regular round configuration, rod shaped
	Aneurinibacillus aneurinilyticus	Brownish with raised elevation, and regular round configuration, rod shaped
Chickpea 2	*Micrococcus* spp.	Orange with flat elevation, and regular round configuration, round shaped (cocci)
	Trichosporon asahii	White and cracked in the middle with smooth and shiny edges
Starch	*Leuconostoc* sp.	White with flat elevation, and regular round configuration, cocci/coccobacilli
	Bacillus licheniformis	White with raised elevation, wavy and smooth edges, rod shaped
	Staphylococcus lentus	Transparent with raised elevation, and regular round configuration, round shaped (cocci)
	Citrobacter freundii	Transparent with raised elevation, irregular shape with twisted edges, rod shaped
	Cryptococcus humicola	Yellowish with raised elevation, round shape with jagged edges
	Geotrichum klebahnii	White with flat elevation, filamentous shape with jagged edges
	Candida krusei	White with raised elevation, and regular round configuration

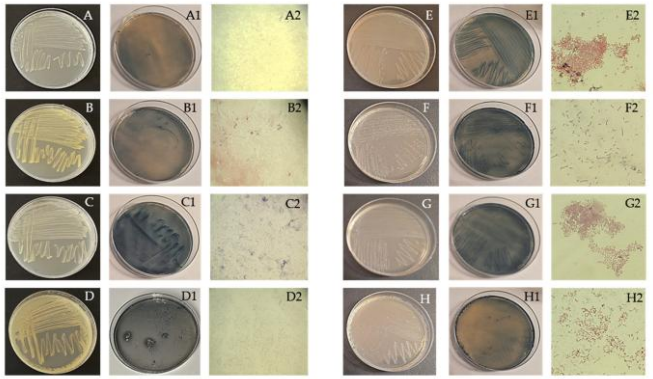


Figure 2. Obtained pure cultures by streaking method, cultures stained with Sudan Black dye, and microphotographs of Gram staining of bacteria isolates *Brevibacillus* sp. (**A**,**A1**,**A2**), *Empedobacter brevis*; (**B**,**B1**,**B2**), *Aneurinibacillus aneurinilyticus*; (**C**,**C1**,**C2**), *Micrococcus* spp.; (**D**,**D1**,**D2**), *Leuconostoc* sp; (**E**,**E1**,**E2**), *Bacillus licheniformis*; (**F**,**F1**,**F2**), *Staphylococcus lentus*; (**G**,**G1**,**G2**), *Citrobacter freundii*; (**H**,**H1**,**H2**), M = 1000×.

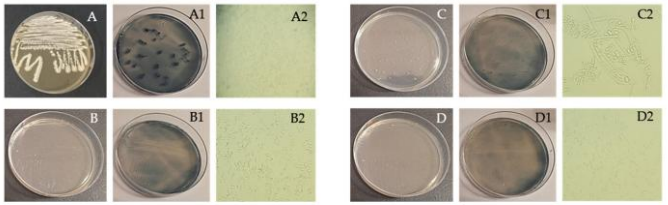


Figure 3. Obtained pure cultures by streaking method, cultures stained with Sudan Black dye, and microphotographs of yeast isolates *Trichosporon asahii* (**A**,**A1**,**A2**), *Cryptococcus humicola*; (**B**,**B1**,**B2**), *Geotrichum klebahnii*; (**C**,**C1**,**C2**), *Candida krusei*; (**D**,**D1**,**D2**), M = 400×.

Identified Bacteria	Gram Staining	KOH Test	Oxidase	Catalase	Nitrate-Reductase
Brevibacillus sp.	+ve	+	+	+	+
Empedobacter brevis	−ve	+	+/−	+	−
Aneurinibacillus aneurinilyticus	+ve	+	+	+	−
Micrococcus spp.	+ve	+	+/−	+	+/−
Leuconostoc sp.	+ve	−	−	-	−
Bacillus licheniformis	+ve	−	−	+	+
Staphylococcus lentus	+ve	−	−	+	+
Citrobacter freundii	−ve	−	−	+	+

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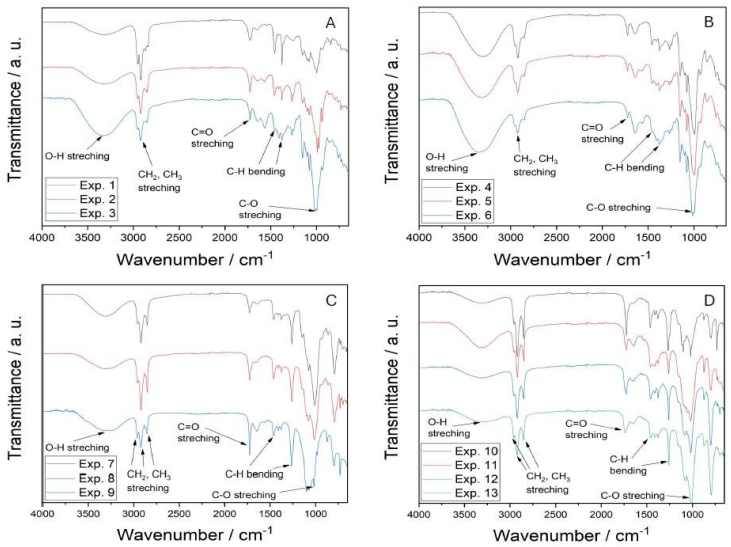
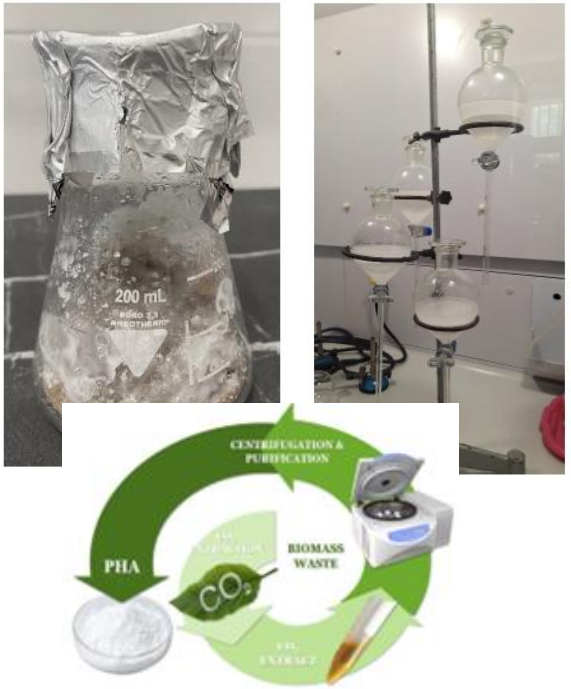
1. Proizvodnja PHA - SSF



Characteristic funcional groups of PHA obtained by FTIR-ATR spectroscopy.

Sample	Wavenumbers / cm^{-1}				
	-OH bond	C-H stretching	C=O stretching	-CH$_2$ bending	C-C stretching
Chickpea 1	3282	2918	1708	1264	1019
		2850			873
Chickpea 2	3281	2919	/	/	1006
		2850			872
Starch	3303	2950	1713	1246	995
		2920			859
Mixture	3290	2956	1711	1267	1076
		2920			1018
		2853			/
Mixture + *C. necator*	3281	2952	1711	1268	1074
		2920			1018
		2849			/



Accumulation of PHA obtained by 5 substrates after 7 days of SSF.

Sample	PHA accumulation / %
Chickpea 1	5.42
Chickpea 2	**13.81**
Starch	5.29
Mixture	4.09
Mixture + C. necator	6.30

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2. Proizvodnja biorazgradljive i kompostabilne ambalaže

PHA

PLA

TPS

Films, 100 µm

Addition of compostable coatings

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University of Zagreb Faculty of Chemical Engineering and Technology

PTF Podravka ROTOPLAST

DOBIVANJE FILMOVA

The Brabender Univex is a universally applicable downstream device for draw-off, cooling and winding of flat films with film speeds up to 30 m/min.

Financira Europska unija NextGenerationEU

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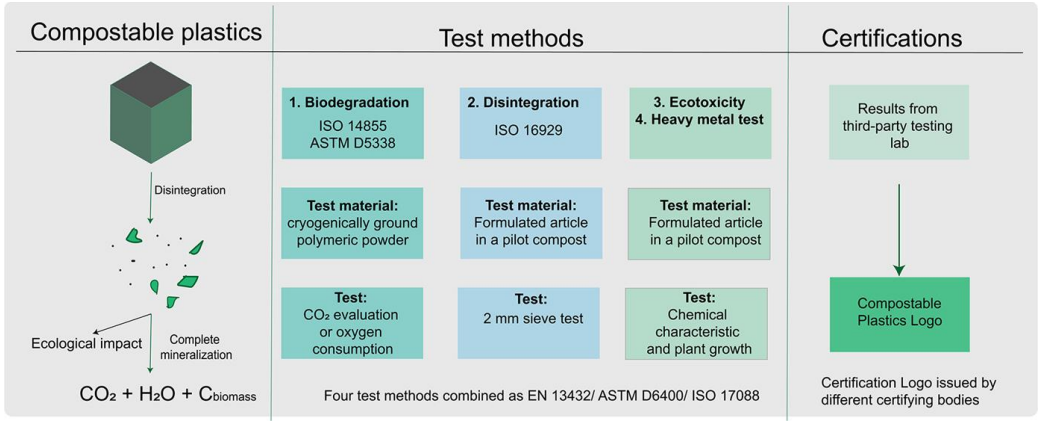
University of Zagreb Faculty of Chemical Engineering and Technology

PTF Podravka ROTOPLAST

DOBIVANJE FILMOVA



ISO 17556:2019
Plastics — Determination of the ultimate aerobic biodegradability of plastic materials in soil by measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved

ISO 14852:2021
Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium — Method by analysis of evolved carbon dioxide

ODREĐIVANJE BIORAZGRADLJIVOSTI

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Home composting vs. industrial composting

	Industrial composting (EN13432)	**Home composting (Vinçotte certification)**
Biodegradation	Test at 58°C in 180 days Biodegradation min. 90%	Test at 20–30°C in 365 days Biodegradation min. 90%
Disintegration	Test at 58°C in 90 days Sieve 2 mm mesh Disintegration > 90% Max 10% of dry weight allowed to be retained by 2 mm sieve	Test at 20–30°C in 180 days Sieve 2 mm mesh Disintegration > 90% Max 10% of dry weight allowed to be retained by 2 mm sieve
Certification	Din Certco/OK Compost	OK Home

Source: Song *et al*. 2009. The seedling logo and the OK Home Compost logo illustrated in the Table are shown by courtesy, respectively, of the European Bioplastics Association and Vincotte.

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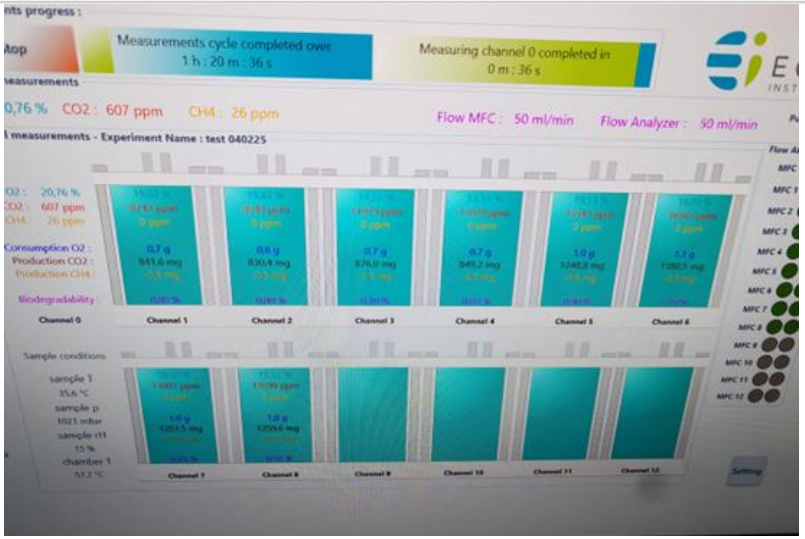
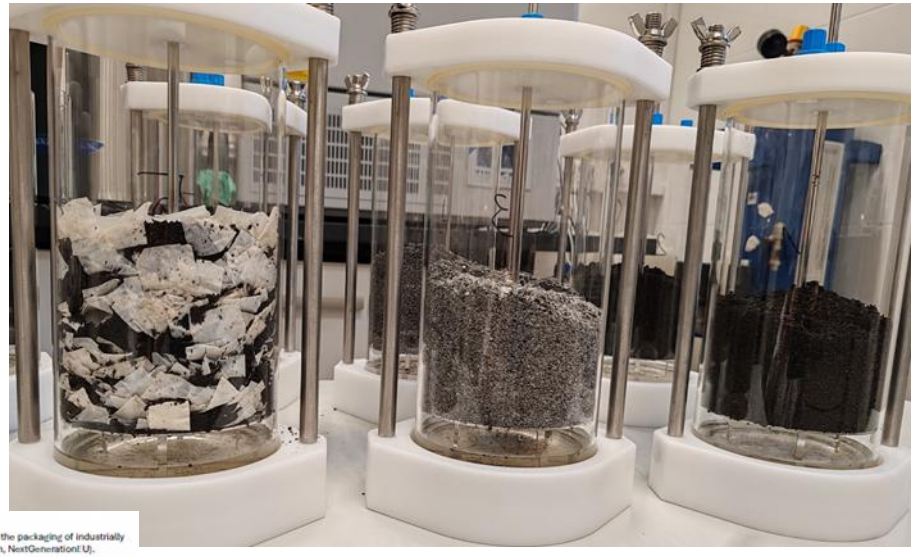
ODREĐIVANJE BIORAZGRADLJIVOSTI MATERIJALA





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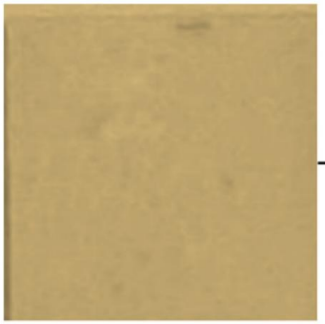
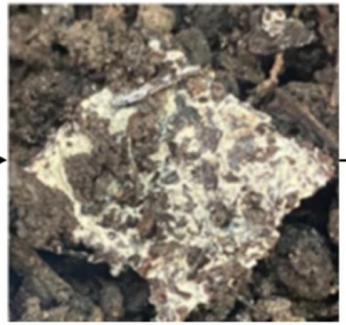
BIORAZGRADLJIVOST

Regular edges

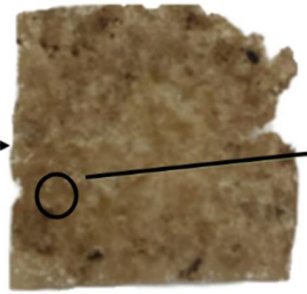


Before biodegradation
TPS_SL/PLA 60/40



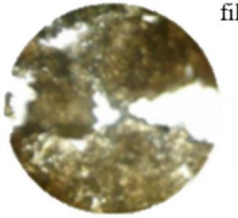
After 7 days of biodegradation in soil
TPS_SL/PLA 60/40

The edges of the material have been degraded by microorganisms.



After 7 days of biodegradation – wahed with water and 70% of ethanol

Visible cracks are discernible within the film.



Microphotograph - polarazing optical microscope 400 x

Polarazing optical microscope

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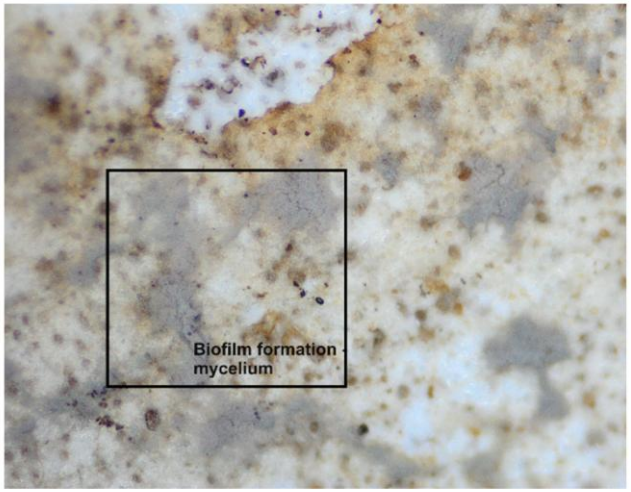
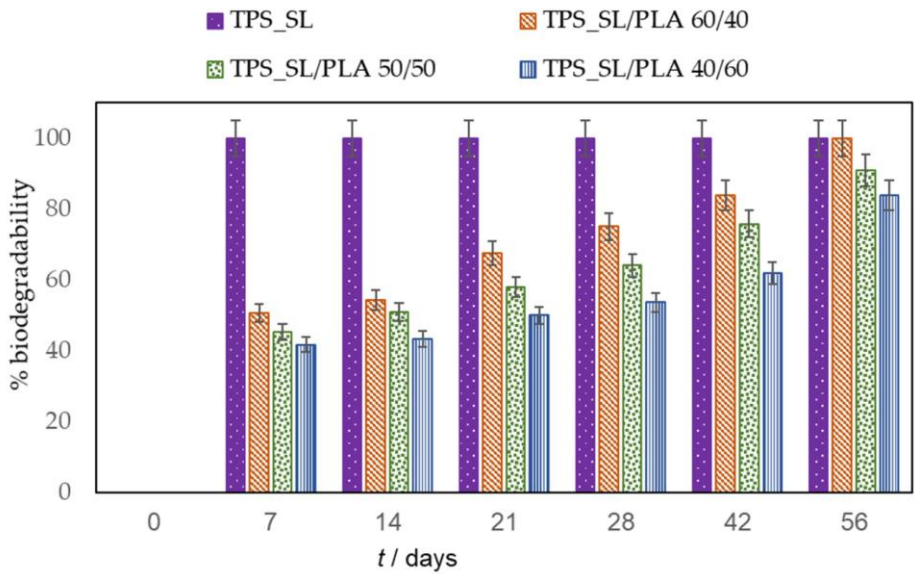
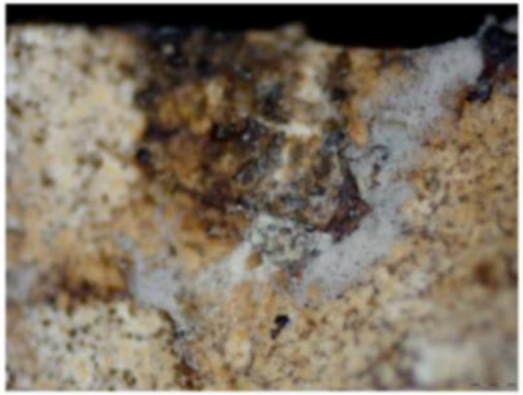
BIORAZGRADNJA BIOPLASTIKE

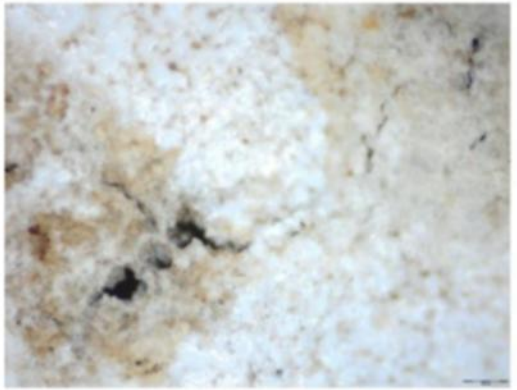






TPS_SL_5CA/PLA 60/40

TPS_SL_5CA/PLA 50/50



TPS_SL_5CA/PLA 40/60

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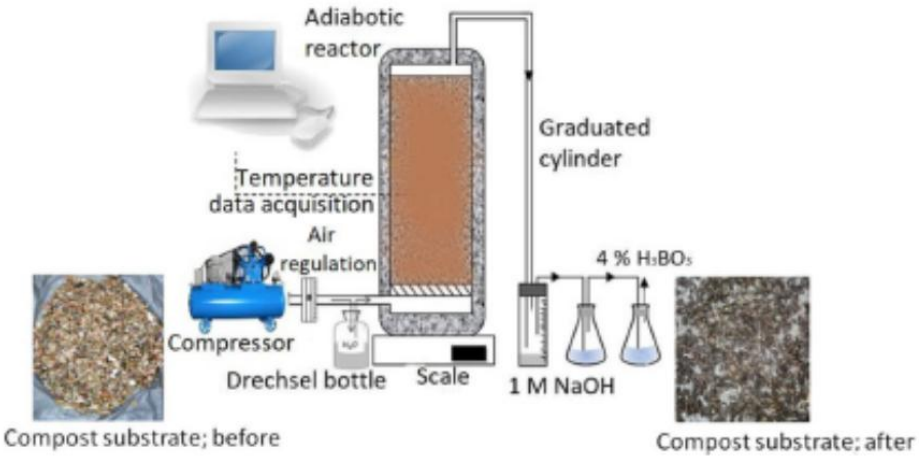
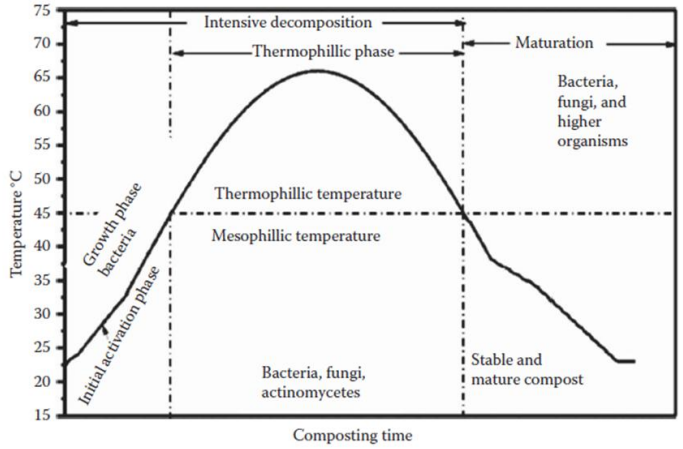
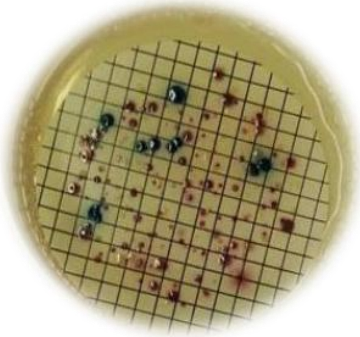
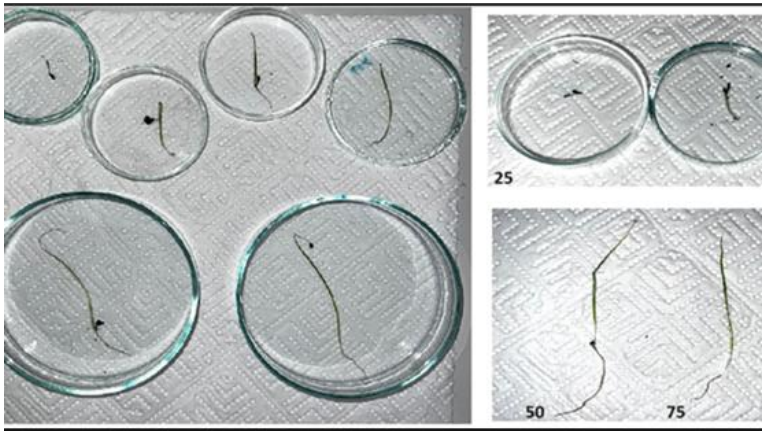
DEZINTEGRACIJA







FITOTOKSIČNOST



% Germination = number of germinated seeds in contaminated test soil / number of germinated seeds in control 100

ISO 18763:2016 Soil quality — Determination of the toxic effects of pollutants on germination and early growth of higher plants

Challenges

System perspective: LCA of Bio-based vs conventional plastics

- Assessment of bio-based plastics vs conventional ones
- Ensure feedstock sustainability for bio-based plastics
- Compostable and biodegradable plastics vs. conventional ones
- Impacts on society (e.g. health) and environment along the life cycle

Projects' contribution to EU policies

- Limit the use of biodegradable plastics in the open environment to specific applications for which reduction, reuse, and recycling are not feasible . Projects' point of view.
- What role for biobased and biodegradable plastics in reaching the 2030 targets of the EU Zero Pollution Action Plan
- Recommendations and research data from projects to support EU policies
- How to shorten the gap between projects' outcomes and policies?

End-of-Life options (biodegradability, ecotoxicity, recyclability, leakage, etc.)

- Complexity of the biodegradation processes in open environment (e.g. marine environment)
- Measurements, metrics and standards for the biodegradation in the open environment
- Safety / toxicity issues (including use of additives in biodegradable plastics)
- Recyclability of bio-based plastics (e.g. creation of value chain, market volumes)

Raising awareness, stakeholder engagement, collaboration and coordination

- Scientific knowledge transfer to relevant actors (policymakers, industry and society)
- Connect initiatives at local, national, and EU level
- Mobilize citizens and society for the scale-up of solutions (from niche to norm)
- End-users' behaviour and impacts of bio-based and biodegradable plastics (e.g. awareness, acceptance, unintentional and mismanaged disposal)

By Glaukos/FVA - New Media Research

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Thank you
for your
attention